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(54) **LIGHT EMITTING DEVICE WITH LOW VOLTAGE-ENDURANCE COMPONENTS**

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(71) Applicant: **TM TECHNOLOGY, INC**, Hsinchu (TW)
(72) Inventors: **Kuo-Tso Chen**, Taipei (TW);
Chi-Cheng Chao, Kaohsiung (TW);
Chih-Yueh Yen, Hsinchu County (TW)

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(73) Assignee: **TM TECHNOLOGY, INC**, Hsinchu (TW)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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Primary Examiner — Thuy Vinh Tran
(74) *Attorney, Agent, or Firm* — Maschoff Brennan

Related U.S. Application Data

(60) Provisional application No. 62/181,486, filed on Jun. 18, 2015.

(57) **ABSTRACT**

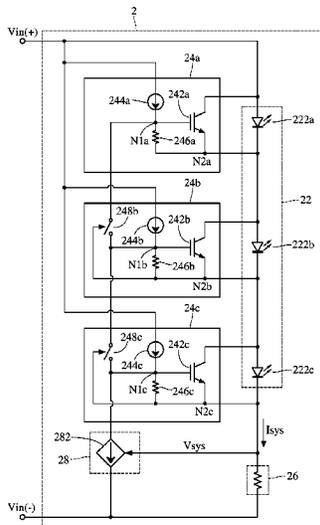
(51) **Int. Cl.**
H05B 37/02 (2006.01)
H05B 33/08 (2006.01)

(52) **U.S. Cl.**
CPC **H05B 33/083** (2013.01)

(58) **Field of Classification Search**
CPC H05B 33/083; H05B 33/0848
USPC 315/185 R, 291, 307, 308, 309
See application file for complete search history.

A light emitting device with low voltage-endurance components includes a light emitting diode string, M first control circuits, a detection unit and a current control circuit. The light emitting diode string includes M first light emitting diodes connected in series. Each first control circuit includes a first switch. One end of the light emitting string is coupled to a node of an input voltage. The first switch is connected to its related first light emitting diode in parallel and can enable a bypass current path. The detection unit detects the potential of the input voltage to produce a current detection signal. The current control circuit is coupled to the M-th one of the M first control circuits and the detection unit and controls the M-th one of the M first control circuits to selectively enable the bypass current path according to the current detection signal.

21 Claims, 10 Drawing Sheets



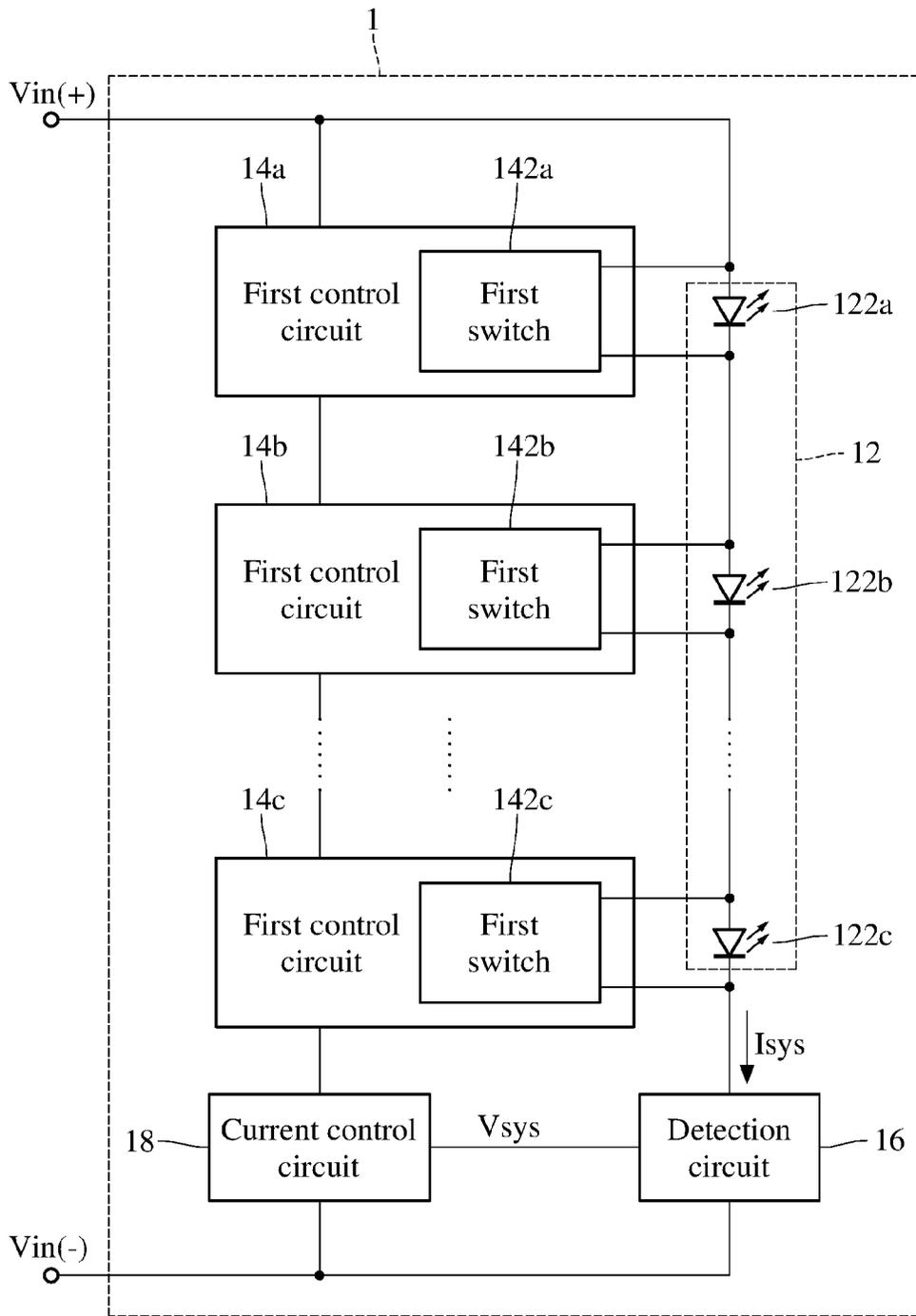


FIG. 1

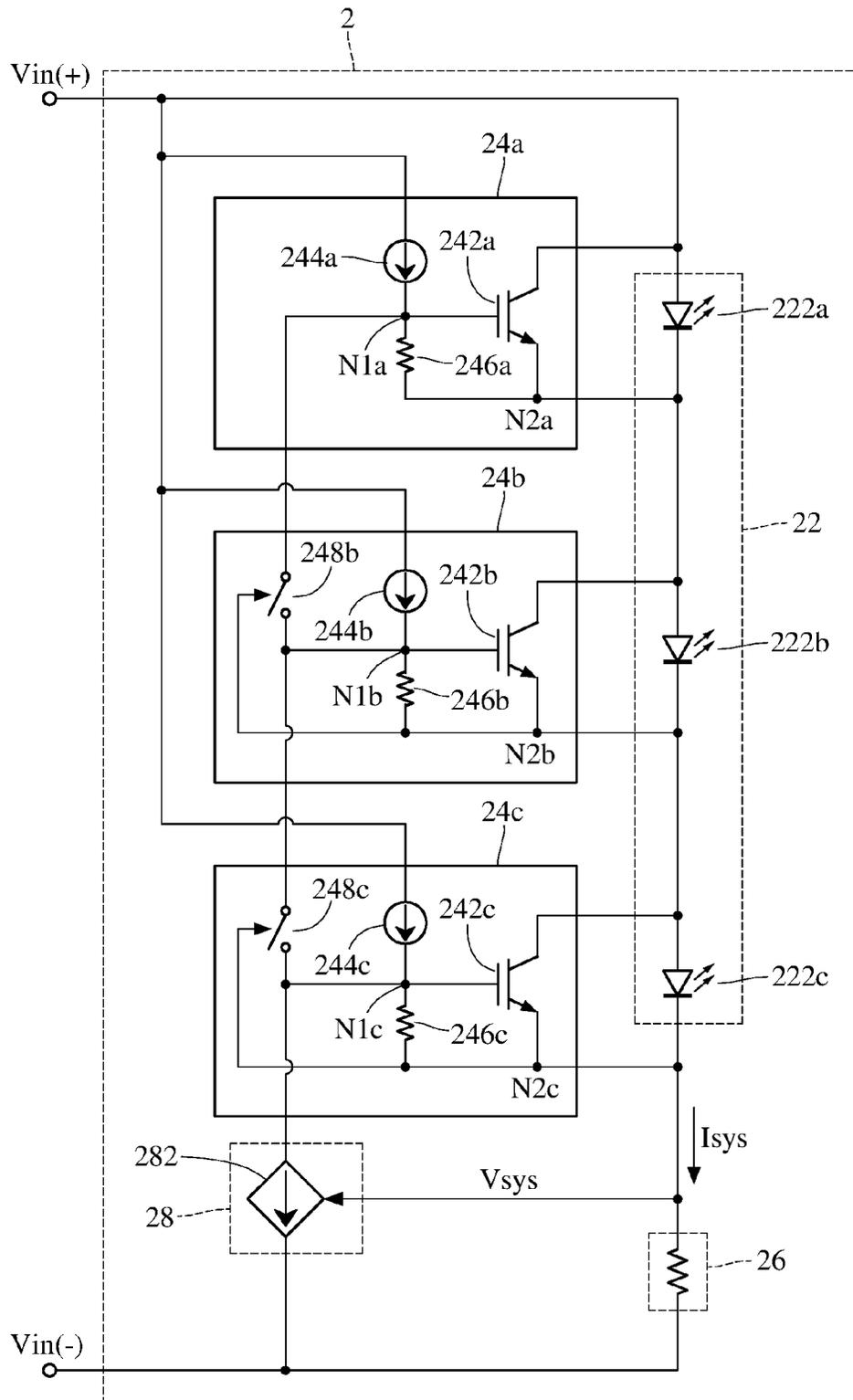


FIG. 2

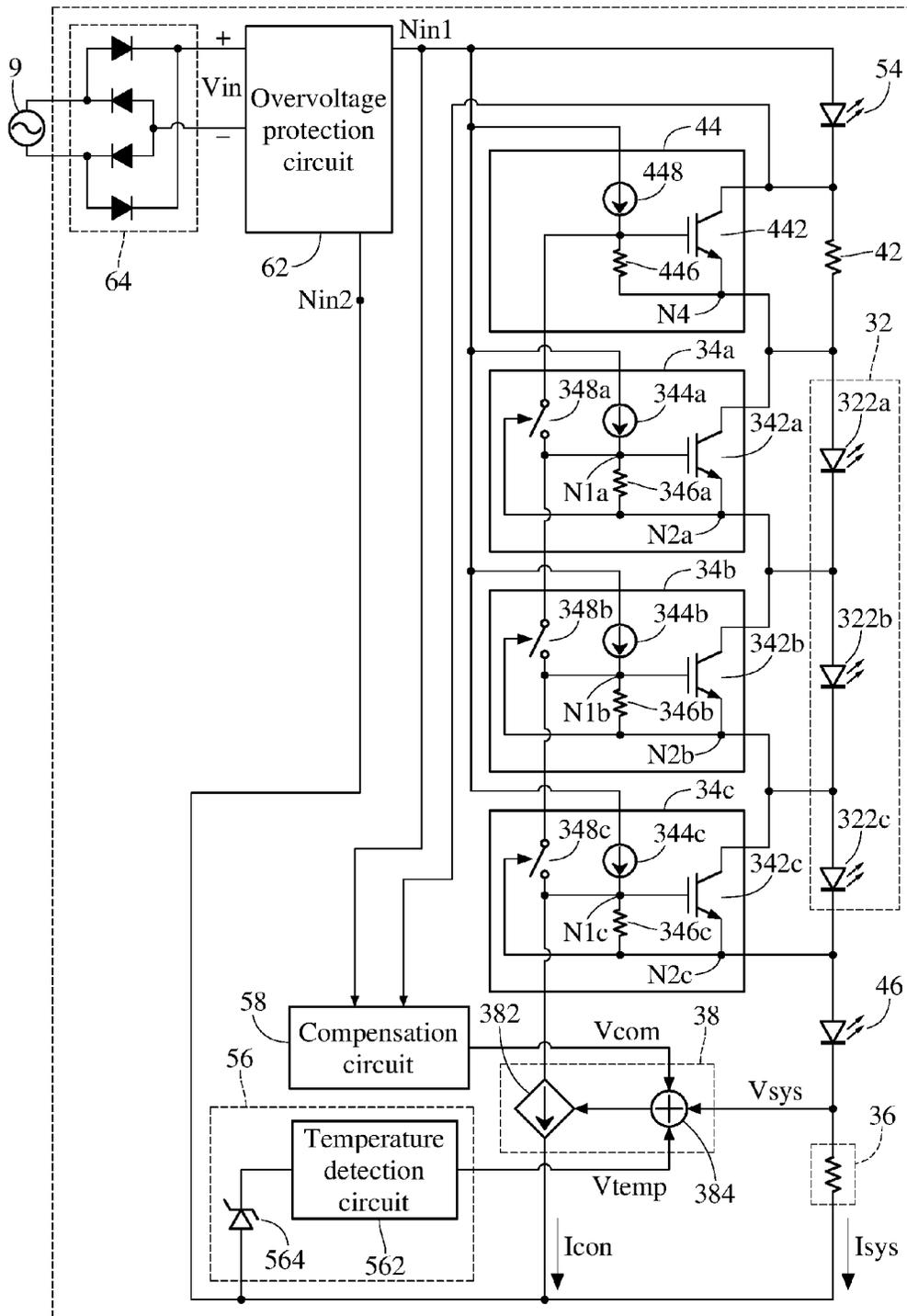


FIG. 3

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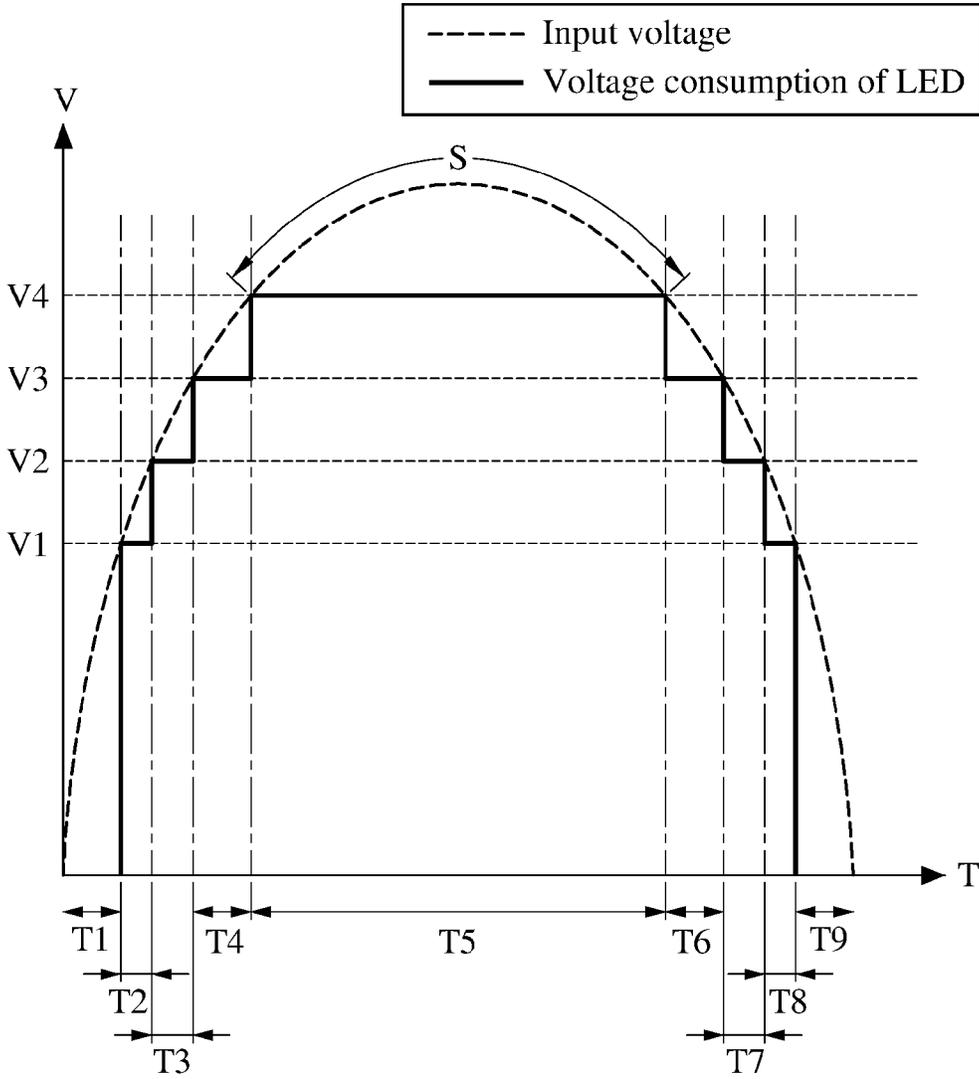


FIG. 4

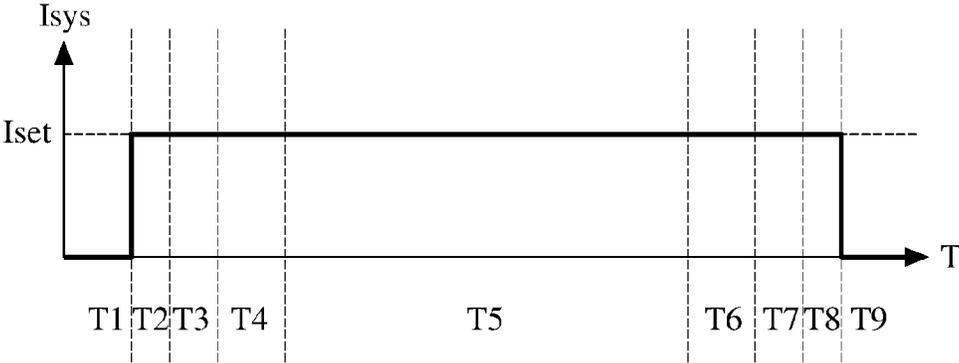


FIG. 5A

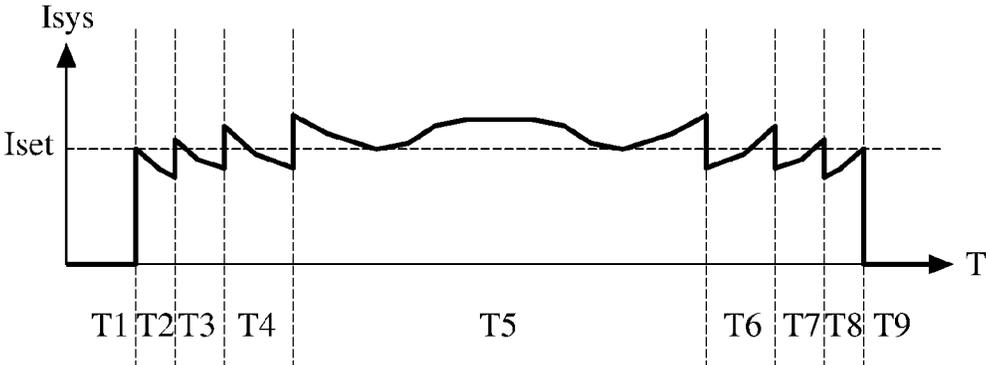


FIG. 5B

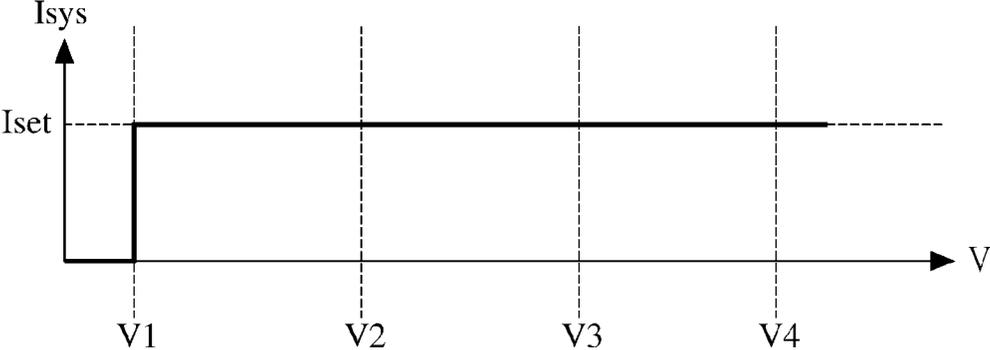


FIG. 6A

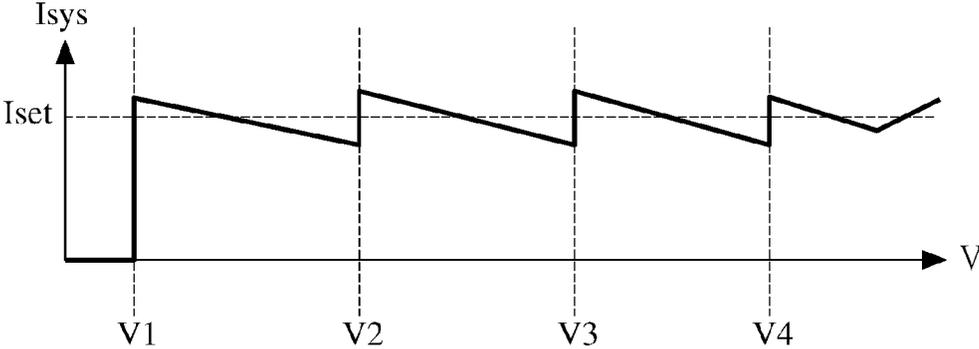


FIG. 6B

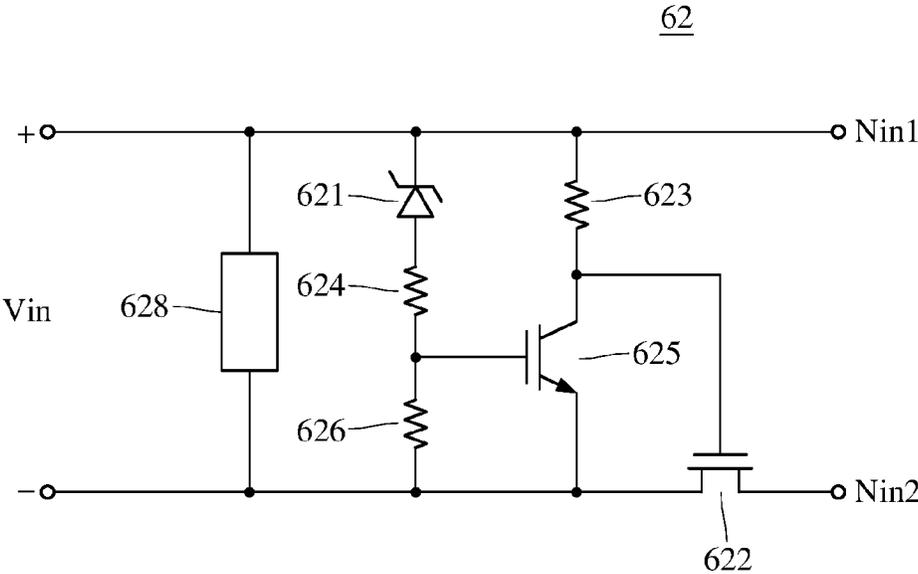


FIG. 7

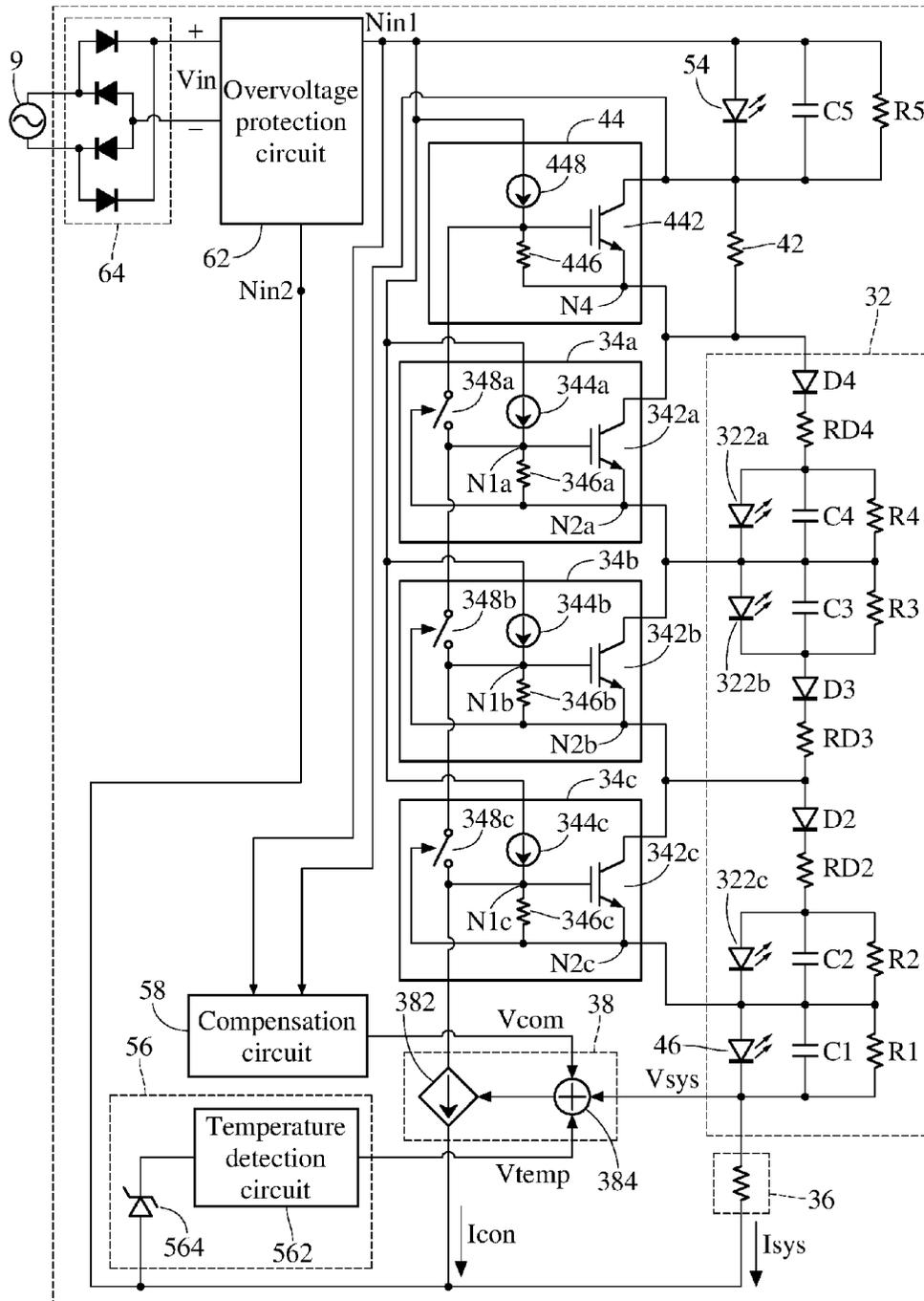


FIG. 8

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LIGHT EMITTING DEVICE WITH LOW VOLTAGE-ENDURANCE COMPONENTS**CROSS-REFERENCE TO RELATED APPLICATIONS**

This non-provisional application claims priority under 35 U.S.C. §119(a) on Patent Application No. 62/181,486 filed in the United States on Jun. 18, 2015, the entire contents of which are hereby incorporated by reference.

BACKGROUND**Technical Field**

The disclosure relates to a light emitting device, more particularly to a light emitting device emitting light via one or more light emitting diodes.

Related Art

Light emitting diodes (LED) are characterized by having a relatively-long lifespan, a relatively-small size, a relatively-good earthquake-resistant ability, relatively-low thermal production and relatively-low power consumption, so recently they have been used as indicators or light sources in a variety of equipment. Moreover, multicolor and high-brightness light emitting diodes are being developed and applied to larger outdoor billboards, traffic lights and relevant fields. In the future, it is very possible to use light emitting diodes as the main illumination light sources with power saving and environmental protection functions.

However, as a conventional light emitting device using a light emitting diode string to provide a light source, light emitting diodes in the light emitting diode string were typically turned on in a specific order, so components respectively corresponding to the light emitting diodes needed to bear a relatively-high voltage difference between their two ends. Therefore, these components in such a conventional light emitting device usually have high voltage-endurance. Also, since a high voltage-endurance component requires a relatively-low working current, the light emitting device would need more or larger high voltage-endurance components. This manner brought in the limitation in the circuit design and led to a higher manufacturing cost of the light emitting device.

SUMMARY

According to one or more embodiments, a light emitting device with one or more low voltage-endurance components includes a light emitting diode string, M first control circuits, a detection circuit and a current control circuit. The light emitting diode string includes M first light emitting diodes connected in series, and each first control circuit includes a first switch. One end of light emitting diode string is coupled to a node of an input voltage. The current control circuit is coupled to the M-th one of the M first control circuits and the detection circuit. The first switch is connected to the first light emitting diode corresponding to the first switch and is applicable to selectively enable a bypass current path. The detection circuit is applicable to detect a total current, flowing through one or more of the light emitting diodes and one or more switches respectively connected to the one or more of the light emitting diodes in parallel, to produce a current detection signal. The current control circuit, according to the current detection signal, controls the M-th one of the M first control circuits whether to provide a preset voltage to the first switch in the M-th one of the M first control circuits, so as to selectively enable the bypass current

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path. When the first switch in the M-th one of the M first control circuits does not enable the bypass current path, the M-th one of the M first control circuits further, in response to the potential of the input voltage, selectively controls the (M-1)th one of the M first control circuits to provide the preset voltage to the first switch in the (M-1)th one of the M first control circuits. M is a positive integer larger than 1.

In another embodiment, when the first switch in the i-th one of the M first control circuits does not enable the bypass current path, the i-th one of the M first control circuits, according to the total current, selectively controls the (i-1)th one of the M first control circuits to provide the preset voltage to the first switch in the (i-1)th one of the M first control circuits, and i is a positive integer larger than 1 but not larger than M. Moreover, the i-th one of the M first control circuits further includes a constant current source, a first resistor and a second switch. The constant current source has two ends respectively coupled to the node of the input voltage and a first node. The first resistor has two ends respectively coupled to the first node and a second node. The second switch is coupled to the first node and the first node of the (i-1)th one of the M first control circuits and is controlled by the potential of the second node to selectively enable the connection between the first node of the i-th one of the M first control circuits and the first node of the (i-1)th one of the M first control circuits. In addition, when the potential of the second node of the i-th one of the M first control circuits is higher than a related threshold, the second switch in the i-th one of the M first control circuits is turned on and the current control circuit, in response to the current detection signal, causes that the output current of the constant current source in the (i-1)th one of the M first control circuits flows to the current control circuit after flowing through the second switch in the i-th one of the M first control circuits.

According to an embodiment, a light emitting device with one or more low voltage-endurance components includes a light emitting diode string and M first control circuits. The light emitting diode string includes M first light emitting diodes, a second light emitting diode and a third light emitting diode. Each first control circuit includes a first switch. The M first light emitting diodes are connected in series in an order, the second light emitting diode is coupled to the M-th one of the M first light emitting diodes, and the third light emitting diode has two ends respectively coupled to the first one of the M first light emitting diodes and a node of an input voltage. The first switch is connected to the corresponding first light emitting diode and selectively enables a bypass current path with accordance to the control of the first control circuit. When the input voltage is larger than a first threshold, the second light emitting diode and the third light emitting diode emit light according to a current caused by the input voltage. When the input voltage is larger than a second threshold larger than the first threshold, the M first control circuits selectively enable M bypass current paths. M is a positive integer larger than 1.

In another embodiment, the light emitting device further includes a detection circuit and a current control circuit. The detection circuit detects a total current, flowing through one or more of the light emitting diodes and one or more switches connected to the one or more light emitting diodes in parallel to produce a current detection signal. The current control circuit is coupled to the M-th one of the M first control circuits and the detection circuit. The current control circuit, according to the current detection signal, controls the M-th one of the M first control circuits whether or not to turn on the first switch in the M-th one of the M first control

circuits, so as to selectively enable the bypass current path. Moreover, when the first switch in the i -th one of the M first control circuits does not enable the bypass current path, the i -th one of the M first control circuits, according to the potential of the input voltage, selectively controls the $(i-1)$ th one of the M first control circuits to provide the preset voltage to the first switch in the $(i-1)$ th one of the M first control circuits, and i is a positive integer larger than 1 but not larger than M . The i -th one of the M first control circuits further includes a constant current source, a first resistor and a second switch. The two ends of the constant current source are respectively coupled to the node of the input voltage and a first node. The two ends of the first resistor are respectively coupled to the first node and a second node. The second switch is coupled to the first node of the i -th one of the M first control circuits and the first node of the $(i-1)$ th one of the M first control circuits and is controlled by the potential of the second node to selectively enable the connection between the first node of the i -th one of the M first control circuits and the first node of the $(i-1)$ th one of the M first control circuits to selectively form a branch path. When the potential of the second node of the i -th one of the M first control circuits, provided by the division of the input voltage, is larger than a related threshold, the i -th one of the M first control circuits turns on a related branch path, and the current control circuit, according to the current detection signal, causes that the output current of the $(i-1)$ th one of the M first control circuits flows to the $(i-1)$ th branch path.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only and thus are not limitative of the present disclosure and wherein:

FIG. 1 is a functional block diagram of a light emitting device in an embodiment of the disclosure;

FIG. 2 is schematic circuit diagram of the light emitting device in an embodiment of the disclosure;

FIG. 3 is schematic circuit diagram of a light emitting device in another embodiment of the disclosure;

FIG. 4 is a schematic diagram of the input voltage of the light emitting device versus the voltage consumption of the light emitting diode string in an embodiment of the disclosure;

FIG. 5A is a schematic diagram of time versus an ideal current flowing through the light emitting diode string in FIG. 2;

FIG. 5B is a schematic diagram of time versus a practical current flowing through the light emitting diode string in FIG. 2;

FIG. 6A is a schematic diagram of voltage versus an ideal current flowing through the light emitting diode string in FIG. 2;

FIG. 6B is a schematic diagram of voltage versus a practical current flowing through the light emitting diode string in FIG. 2;

FIG. 7 is schematic circuit diagram of the overvoltage protection circuit in an embodiment of the disclosure; and

FIG. 8 is schematic circuit diagram of the light emitting device in another embodiment of the disclosure.

DETAILED DESCRIPTION

In the following detailed description, for purposes of explanation, numerous specific details are set forth in order

to provide a thorough understanding of the disclosed embodiments. It will be apparent, however, that one or more embodiments may be practiced without these specific details. In other instances, well-known structures and devices are schematically shown in order to simplify the drawings.

Please refer to FIG. 1. FIG. 1 is a functional block diagram of a light emitting device in an embodiment of the disclosure. As shown in the figure, a light emitting device 1 with one or more low voltage-endurance components includes a light emitting diode string 12, a plurality of first control circuits 14a~14c, a detection circuit 16 and a current control circuit 18. The light emitting diode string 12 includes first light emitting diodes 122a~122c connected in series. The first control circuits 14a~14c respectively include first switches 142a~142c. One end of the light emitting diode string 12 is coupled to a node of an input voltage V_{in} . The first switches 142a~142c are connected to the first light emitting diodes 122a~122c in parallel, respectively. The current control circuit 18 is coupled to the first control circuit 14c and the detection circuit 16. In practice, the light emitting device 1 could include M first light emitting diodes and M first control circuits respectively corresponding to the M first light emitting diodes, and M is a positive integer larger than 1. For a concise description, the first light emitting diodes 122a~122c are exemplified to explain the disclosure, and however, the amount of first light emitting diodes is not limited thereto.

The first control circuits 14a~14c are applicable to selectively enable one or more bypass current paths for one or more of the first light emitting diodes 122a~122c. Particularly, one or more of the first control circuits 14a~14c provide a preset voltage to one or more of the first switches 142a~142c, and if one of the first switches 142a~142c receives the preset voltage, this first switch is turned on so that a related bypass current path is formed. In the figure, the first switches 142a~142c are respectively connected to the first light emitting diodes 122a~122c in parallel, and when one or more of the first switches 142a~142c are turned on, a current will flow through one or more related bypass current paths instead of flowing through corresponding one or more of the first light emitting diodes 122a~122c. Therefore, the one or more first light emitting diodes through which the current does not flow will not emit light.

The detection circuit 16 is applicable to detect a total current I_{sys} that flows through one or more light emitting diodes and one or more corresponding switches, to produce a current detection signal V_{sys} . In this embodiment, the detection circuit 16, according to the current I_{sys} , produces the current detection signal V_{sys} . For example, the detection circuit 16 is a resistor, the current I_{sys} is a current flowing through the light emitting diode string 12, and the current detection signal V_{sys} is a voltage signal produced when the current I_{sys} flows through the detection circuit 16. In practice, a person of ordinary skill in the art can, in view of the disclosure, design the detection manner of the detection circuit 16 or replace the voltage type of the current detection signal V_{sys} by the current type or other types of the current detection signal V_{sys} according to actual requirements, and the disclosure has no limitation in these possible changes.

The current control circuit 18 is applicable to in response to the current detection signal V_{sys} , control the first control circuit 14c whether to provide the preset voltage to the first switch 142c, so as to selectively turn on the first switch 142c to enable the related bypass current path.

If the first control circuit 14c controls the first switch 142c not to enable the related bypass current path, the first control

circuit **14c**, according to the potential of the input voltage V_{in} , selectively controls the first control circuit **14b** to provide a preset voltage to the first switch **142b**, so as to selectively enable a related bypass current path. More particularly, when the input voltage V_{in} is larger than its related threshold, the first control circuit **14c** will control the first control circuit **14b** to turn off the first switch **142b**, so the related bypass current path will not be enabled. As described above, since the current flows through the first light emitting diode **122b**, the first light emitting diode **122b** emits light.

Likewise, when the first switch **142b** in the first control circuit **14b** does not enable its related bypass current path, the first control circuit **14b**, according to the potential of the input voltage V_{in} , selectively controls the first control circuit **14a** to provide a preset voltage to the first switch **142a**. A person of ordinary skill in the art can understand that in the case of the light emitting device **1** including the M first control circuits and the M first light emitting diodes, when the i -th one of the M first control circuits does not enable its related bypass current path, the i -th one of the M first control circuits will, according to the potential of the input voltage V_{in} , selectively control the $(i-1)$ th one of the M first control circuits to enable its related bypass current path, where i is a positive integer larger than 1 but not larger than M .

Please refer to FIG. 2 to introduce the circuit of the light emitting device more detailed. FIG. 2 is schematic circuit diagram of the light emitting device in an embodiment of the disclosure. As shown in FIG. 2, in a light emitting device **2** with one or more low voltage-endurance components, each of the first control circuits **24a~24c** further includes more elements. In the case of the first control circuit **24c**, the first control circuit **24c** further includes a constant current source **244c**, a first resistor **246c** and a second switch **248c**. In this embodiment, the current control circuit **28** includes a voltage-controlled current source **282**.

The constant current source **244c** has two ends respectively coupled to the node of the input voltage V_{in} and a first node $N1c$. The two ends of the first resistor **246c** are respectively coupled to the first node $N1c$ and the second node $N2c$. The second switch **248c** is coupled to the first node $N1c$ and the first node $N1b$ of the first control circuit **24b**. The second switch **248c** is controlled by the potential of the second node $N2c$ to selectively enable the connection between the first node $N1c$ and the first node $N1c$, so as to selectively enable a related branch path. The potential of the second node $N2c$ is a division of the input voltage V_{in} to the second node $N2c$.

The two ends of the first switch **242c** are electrically connected to the second node $N2c$ and the second node $N2b$ of the first control circuit **24b**, respectively, and the control end of the first switch **242c** is coupled to the first node $N1c$. In the figure, the cathode end of the first light emitting diode **222c** is coupled to the second node $N2c$, and the anode end of the first light emitting diode **222c** is coupled to the second node $N2b$. Therefore, the first switch **242c** is controlled by the potential of the first node $N1c$ to selectively enable the bypass current path between the second node $N2c$ and the second node $N2b$.

In the embodiment shown in FIG. 2, the first light emitting diodes **222a~222c** respectively have their own thresholds. When the input voltage V_{in} is larger than a threshold corresponding to one of the first light emitting diodes **222a~222c**, the corresponding one of the first light emitting diodes **222a~222c** will be driven to emit light. Moreover, the thresholds respectively corresponding to the first light emitting diodes **222a~222c** are set from the largest one to the smallest one. Therefore, with the increase of the input

voltage V_{in} , the first one to be turned on is the first light emitting diode **222c**, the second one is the first light emitting diode **222b**, and the last one is the first light emitting diode **222a**.

More particularly, when a division of the input voltage V_{in} to the second node $N2c$ is larger than a related threshold, the first control circuit **24c** enables a related branch path and the current control circuit **28** correspondingly increases the current value of the control current I_{con} according to the current detection signal V_{sys} , so the output current of the first control circuit **24b**, i.e. the output current of the constant current source **244b**, flows to the branch path in the first control circuit **24c**. Therefore, the first switch **242b** is turned off, and the first light emitting diode **222b** then emits light. When the first control circuit **24c** does not enable its related branch path, the output current of the constant current source **244b** in the first control circuit **24b** flows through the first resistor **246b** to provide a preset voltage to the first node $N1b$, so the first switch **242b** is turned on to enable its related bypass current path. Therefore, the first light emitting diode **222b** does not emit light.

In other words, when the potential of the input voltage V_{in} successively increases, the first control circuit **24c**, according to the input voltage V_{in} and the control current I_{con} , selectively provides a related bypass current path and the first control circuits **24c** and **24b** also enable their related branch paths in turn according to the input voltage V_{in} . Meanwhile, the current control circuit **28** correspondingly increases the current value of the control current I_{con} on the related branch path, so as to enable the first light emitting diode **222b** or **222a**. Similarly, when the potential of the input voltage V_{in} successively decreases, the first control circuits **24b** and **24c** cut off their related branch paths in turn according to the input voltage V_{in} and the current control circuit **28** correspondingly decreases the current value of the control current I_{con} . Therefore, the first light emitting diodes **222a** and **222b** are turned off in turn. Finally, the first control circuit **24c**, according to the input voltage V_{in} and the control current I_{con} , provides the related bypass current path so that the first light emitting diode **222c** is turned off.

Please refer to FIG. 3 to illustrate another embodiment of the light emitting device. FIG. 3 is schematic circuit diagram of a light emitting device in another embodiment of the disclosure. As compared to the previous embodiment, a light emitting device **3** with one or more low voltage-endurance components further includes a second resistor **42**, a second control circuit **44**, a second light emitting diode **46**, a third light emitting diode **54**, a temperature detection circuit **56**, a compensation circuit **58**, an overvoltage protection circuit **62** and a rectification circuit **64**. In addition to a voltage-controlled current source **382**, the current control circuit **38** also includes a voltage adder **384**. Note that in practice, only a part of the above components may be included in the light emitting device **3**, and it is not necessary for the light emitting device **3** to use all of the above components for its normal operation. In this embodiment, the second control circuit **44** has a structure similar to the structure constituted by the first control circuits **34a~34c**, so only the main part of the second control circuit **44** will be described later but the other part of the second control circuit **44** will not be described.

Following the previous description, the second resistor **42** has two ends respectively coupled to the light emitting diode string **32** and the node of the input voltage V_{in} . The second control circuit **44** is coupled to a first light emitting diode **322a**. The second control circuit **44** includes a third switch **442** connected to the second resistor **42** in parallel. The

second light emitting diode 46 has two ends respectively connected to the light emitting diode string 32 and the detection circuit 36. The third light emitting diode 54 has two ends respectively connected to the node of the input voltage V_{in} and the second resistor 42. The temperature detection circuit 56 has two ends respectively coupled to the voltage adder 384 and the node of the input voltage V_{in} . The compensation circuit 58 is connected to the third light emitting diode 54 in parallel and is coupled to the voltage adder 384. The voltage adder 384 is coupled to the voltage-controlled current source 382. The overvoltage protection circuit 62 is coupled to the node of the input voltage V_{in} . The rectification circuit 64 is coupled to an AC power source 9 to produce the input voltage V_{in} . The rectification circuit 64 is, for example, a bridge rectifier, a rectification-boost circuit or a rectification-buck circuit.

Please refer to FIG. 4 to illustrate how the light emitting device 3 emits light. FIG. 4 is a schematic diagram of the input voltage of the light emitting device versus the voltage consumption of the light emitting diode string in an embodiment of the disclosure, where the horizontal axis represents time, and the vertical axis represents voltage potential. In this embodiment, the input voltage V_{in} is exemplified by a DC sine-wave voltage produced by the full-wave rectification, but in practice, the input voltage V_{in} is not limited thereto. In FIG. 4, the dotted line represents a voltage waveform of the input voltage V_{in} during a cycle, and the solid lines represent voltages consumed by the first light emitting diodes 322a~322c, the second light emitting diode 46 and the third light emitting diode 54, respectively. FIG. 4 also presents a first time period T1 to a ninth time period T9 and a first voltage potential V1 to a fourth voltage potential V4.

During the first time period T1, the potential of the input voltage V_{in} is smaller than the first voltage potential V1, and all light emitting diodes do not emit light. During the second time period T2, the potential of the input voltage V_{in} is larger than the first voltage potential V1 but smaller than the second voltage potential V2, and the second light emitting diode 46 and the third light emitting diode 54 are turned on to emit light. During the third time period T3, the potential of the input voltage V_{in} is larger than the second voltage potential V2 but smaller than the third voltage potential V3, and the first light emitting diode 322c is turned on to emit light.

Then, during the fourth time period T4 and the fifth time period T5, the potential of the input voltage V_{in} progressively becomes larger than the third voltage potential V3 and then the fourth voltage potential V4, so the first light emitting diodes 322b and 322a are turned on in turn. During the fifth time period T5, the second control circuit 44 does not enable its related bypass current path, so the current I_{sys} can flow through the second resistor 42. Herein, the second resistor 42 is used to consume the superfluous voltage energy corresponding to the curve S shown in FIG. 4, to protect the first light emitting diodes 322a~322c, the second light emitting diode 46 and the third light emitting diode 54. During the sixth time period T6 to the ninth time period T9, the input voltage V_{in} progressively decreases, the light emitting diodes are turned off in an order reverse to the previously-described order.

In view of FIG. 2 to FIG. 4, the luminous period of the second light emitting diode 46 and the luminous period of the third light emitting diode 54 cover the luminous periods of the first light emitting diodes 322a~322c. In other words, the second light emitting diode 46 and the third light emitting diode 54 are turned on earlier than the first light

emitting diodes 322a~322c and are turned off later than the first light emitting diodes 322a~322c. Therefore, during most of a cycle of the input voltage V_{in} , the second light emitting diode 46 and the third light emitting diode 54 continuously emit light. Moreover, the amount of the second light emitting diode 46 and the amount of the third light emitting diode 54 are not limited to one. A person of ordinary skill in the art can in view of the disclosure, design a ratio among the amounts of first light emitting diodes 322a~322c, the amount of the second light emitting diode 46 and the amount of the third light emitting diode 54 according to a variety of actual requirements, to optimize the power consumption and efficiency of the light emitting device 3 or achieve a desired flicker index.

Please refer to FIGS. 5A, 5B, 6A and 6B. FIG. 5A is a schematic diagram of time versus an ideal current flowing through the light emitting diode string in FIG. 2, FIG. 5B is a schematic diagram of time versus a practical current flowing through the light emitting diode string in FIG. 2, FIG. 6A is a schematic diagram of voltage versus an ideal current flowing through the light emitting diode string in FIG. 2, and FIG. 6B is a schematic diagram of voltage versus a practical current flowing through the light emitting diode string in FIG. 2. In FIG. 5A and FIG. 5B, the horizontal axis represents time, and the vertical axis represents current. In FIG. 6A and FIG. 6B, the horizontal axis represents the potential of the input voltage, and the vertical axis represents the value of the current.

As shown in FIG. 5A and FIG. 6A, during the second time period T2 to the eighth time period T8, the current I_{sys} should ideally be maintained at a specific value. Alternatively, even if the input voltage V_{in} changes, the current I_{sys} should still be maintained at a specific value ideally. However, as shown in FIG. 5B and FIG. 6B, the current I_{sys} , in fact, may change with time or the potential of the input voltage V_{in} . Specifically, the current I_{sys} is varied with whether the first switches 342a~342c are turned on or not. In detail, during the second time period T2, the input voltage V_{in} is larger than the cut-in voltage of the second light emitting diode 46 and the cut-in voltage of the third light emitting diode 54, so the current I_{sys} is produced to turn on the second light emitting diode 46 and the third light emitting diode 54. When the input voltage V_{in} progressively increases, more light emitting diodes are sequentially turned on, so the equivalent resistance of the flowing path of the current I_{sys} increases with the increase of the input voltage V_{in} . Because of the increase of such an equivalent resistance of the flowing path, the current I_{sys} , i.e. the division of the input voltage V_{in} by the equivalent resistance, is substantially maintained at a specific value.

More particularly, the current I_{sys} has variations along the constant value axis represented by a preset current value I_{set} as shown in FIG. 5B or FIG. 6B, and the curve of the current I_{sys} relative to the horizontal axis parameter in FIG. 5B is different from the curve of the current I_{sys} relative to the horizontal axis parameter in FIG. 6B since the horizontal axis parameter in FIG. 5B is different from the horizontal axis parameter in FIG. 6B. Such variations of the current I_{sys} can be reasonably deduced according to the description of the specification and figures and the circuit structure in the disclosure by a person of ordinary skill in the art, and thus, they are not described repeatedly. Basically, when the current control circuit 38, according to the current detection signal V_{sys} , determines that the current I_{sys} is larger than a preset current value I_{set} , the current control circuit 38 will increase the current value of the control current I_{con} to turn on the next light emitting diode. Therefore, the current I_{sys}

increases to be slightly larger than the preset current value I_{set} to trigger the current control circuit 38. Then, when the next light emitting diode is turned on, the current I_{sys} decreases to be smaller than the preset current value I_{set} . With the increase of the input voltage V_{in} , the current I_{sys} progressively increases so that the light emitting device 3 repeats the aforementioned action.

Please refer to FIG. 3 again to introduce other elements in the light emitting device 3. The voltage adder 384 is applicable to add a temperature detection signal V_{temp} and a compensation signal V_{com} to the current detection signal V_{sys} . In the embodiment shown in FIG. 3, the voltage-controlled current source 382 adjusts the current value of the control current I_{con} according to such a current detection signal V_{sys} that has contained the temperature detection signal V_{temp} and the compensation signal V_{com} . The larger the voltage potential of the current detection signal V_{sys} , the larger the current value of the control current I_{con} ; and the less the voltage potential of the current detection signal V_{sys} , the less the current value of the control current I_{con} . Therefore, the current control circuit 38 adjusts the current value of the control current I_{con} according to not only the current detection signal V_{sys} but also the temperature detection signal V_{temp} and the compensation signal V_{com} . In an embodiment, the current control circuit 38 adjusts the preset current value I_{set} according to the temperature detection signal V_{temp} , so as to correct the voltage and current values that are drifting with the variations in the system temperature.

The temperature detection circuit 56 includes a temperature detection circuit 562 and a Zener diode 564. One end of the Zener diode 564 is coupled to the node of the input voltage V_{in} , and the temperature detection circuit 562 is coupled to the other end of the Zener diode 564 and the voltage adder 384. The temperature detection circuit 56 is applicable to detect the system temperature to produce the temperature detection signal V_{temp} . When the system temperature is higher than a temperature threshold, the current control circuit 38 adjusts the current value of the control current I_{con} according to the temperature detection signal V_{temp} , so as to control the first control circuits 34a~34c to selectively enable one or more bypass current paths.

The compensation circuit 58 is applicable to generate the compensation signal V_{com} according to the voltage difference between two ends of the third light emitting diode 54. Specifically, the cut-in voltage of a light emitting diode is affected by the fabrication conditions of this light emitting diode, so the compensation circuit 58, according to the voltage difference between the two ends of the third light emitting diode 54, determines that the cut-in voltage of the third light emitting diode 54 is smaller than or larger than a predetermined cut-in voltage, and according to the determination, produces the compensation signal V_{com} to drive the current control circuit 38 to adjust the current value of the control current I_{con} .

Please refer to FIG. 7 introduce an embodiment of the overvoltage protection circuit. FIG. 7 is schematic circuit diagram of the overvoltage protection circuit in an embodiment of the disclosure. The overvoltage protection circuit 62 includes a Zener diode 621, a first resistor 623, a second resistor 624, a third resistor 626, a third switch 622, a fourth switch 625 and an impedance 628, and the connections between these components are shown in FIG. 8. When the potential of the input voltage V_{in} is smaller than the sum of the breakdown voltage of the Zener diode 621 and the turn-on voltage of the fourth switch 625, the fourth switch 625 is turned off but the third switch 622 is turned on.

Herein, the input voltage V_{in} is applied via a node N_{in1} and a node N_{in2} to the follow-up circuit so that the follow-up circuit could normally operate. When the potential of the input voltage V_{in} is larger than the sum of the breakdown voltage of the Zener diode 621 and the turn-on voltage of the fourth switch 625, the fourth switch 625 is turned on so that the third switch 622 is turned on. Herein, the input voltage V_{in} is not applied to the follow-up circuit. For example, the third switch 622 is an N-type metal-oxide-semiconductor field-effect transistor (MOSFET), the fourth switch 625 is a bipolar junction transistor (BJT), and the impedance 628 is a metal oxide varistor (MOV).

Please refer to FIG. 8. FIG. 8 is schematic circuit diagram of the light emitting device in another embodiment of the disclosure. In the embodiment shown in FIG. 8, a light emitting device 3' further includes capacitors C1~C5, resistors R1~R5 and RD2~RD4, and diodes D2~D4 as compared with the light emitting device 3 in FIG. 3.

The capacitor C1, the resistor R1 and the second light emitting diode 46 are connected in parallel. The capacitor C5, the resistor R5 and the third light emitting diode 54 are connected in parallel. Similarly, the capacitors C2~C4, the resistors R2~R4 and the first light emitting diodes 322a~322c are connected in parallel, respectively; in detail, the capacitor C2, the resistor R2 and the first light emitting diode 322c are connected in parallel, the capacitor C3, the resistor R3 and the first light emitting diode 322b are connected in parallel, and the capacitor C4, the resistor R4 and the first light emitting diode 322a are connected in parallel. At another aspect, the capacitors C1~C5, the resistors R1~R5 and the related light emitting diodes are respectively connected in parallel to constitute a plurality of light emitting units electrically connected. As an example, the capacitor C5, the resistor R5 and the third light emitting diode 54 constitute a light emitting unit. A person of ordinary skill in the art can deduce other light emitting units by analogy.

The resistors RD2~RD4 and the diodes D2~D4 are respectively connected in series to constitute series circuits each connected to related one of the above light emitting units in series. At an aspect, the resistors RD2~RD4 and the diodes D2~D4 each connected to related one of the resistors RD2~RD4 in series constitute a plurality of protection units. For example, the resistor RD2 is connected to the diode D2 in series to constitute a protection unit. A protection unit is connected to a light emitting unit in series. The connections among the resistors RD2~RD4 and the diodes D2~D4 in FIG. 7 are an exemplary embodiment, but not used to limit the order or method of connecting the protection units and the light emitting units in series.

The capacitors C1~C5 are used to ease the flickers occurring to the first light emitting diodes 322a~322c, the second light emitting diode 46 and the third light emitting diode 54, respectively. Specifically, as described above, when the input voltage V_{in} progressively increases to be larger than or substantially equal to the sum of the turn-on voltages of the second light emitting diode 46 and the third light emitting diode 54, the second light emitting diode 46 and the third light emitting diode 54 are turned on and the capacitors C1 and C5 respectively store the energy in the turn-on voltage of the second light emitting diode 46 and the energy in the turn-on voltage of the third light emitting diode 54.

When the input voltage V_{in} is larger than or substantially equal to the sum of the turn-on voltages of the diodes 322a~322c, 46 and 54, all the first light emitting diodes 322a~322c, the second light emitting diode 46 and the third light emitting diode 54 are turned on and the capacitors

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C1~C5 respectively store the relative energy in the turn-on voltages of the diodes 322a~322c, 46 and 54 respectively connected to the capacitors C1~C5 in parallel.

When the input voltage V_{in} progressively decreases to be smaller than the sum of the turn-on voltages of the first light emitting diodes 322a~322c, the second light emitting diode 46 and the third light emitting diode 54, the first switch 342a is turned on to enable a bypass current path to the light emitting unit constituted by the first light emitting diode 322a, the capacitor C4 and the resistor R4. Therefore, the capacitor C4 provides electric power to the first light emitting diode 322a to prevent the first light emitting diode 322a from immediately stopping emitting light when the first switch 342a enables its related bypass current path. Likewise, the capacitors C1~C3 and C5 should also do the similar operations and have the similar functions, and they will not repeated hereinafter.

Additionally, the capacitors C1~C5 are capable of maintaining a constant voltage potential to prevent the voltage difference between the two ends of each of the diodes 322a~322c, 46 and 54 from fast increasing or decreasing with the turn-on of the switch 342a, 342b, 342c or 442 and further prevent the luminous brightness of each of the diodes 322a~322c, 46 and 54 from be directly affected. The resistors R1~R5 are used to consume the surplus electric energy stored in the capacitors C1~C5.

The diodes D2~D4 are used to prevent the capacitors C2~C4 from discharging toward the bypass paths enabled by the first switches 342a, 342b and 342c, respectively. The resistors RD2~RD4 are used to prevent the above electric components from being damaged by a large current when the power source is just turned on.

As set forth above, the disclosure provides a light emitting device that detects a current flowing through the light emitting diode string and controls a controllable current source according to the detection result. The controllable current source further drives one or more control modules corresponding to one or more light emitting diodes to selectively enable one or more bypass current paths to one or more related light emitting diodes, so the light emitting diodes in the light emitting diode string are turned on in an order from a node of low voltage potential to a node of high voltage potential. As compared to the conventional method to turn on a light emitting diode string, the voltage difference between the two ends of each switch in the light emitting device in the disclosure is lower, so low voltage-endurance components could be used in the light emitting device. Therefore, the manufacturing cost of the light emitting device may be reduced.

What is claimed is:

1. A light emitting device with one or more low voltage-endurance components, the light emitting device comprising:

a light emitting diode string comprising M first light emitting diodes connected in series, and one end of the light emitting diode string coupled to a node of an input voltage;

M first control circuits, each of which comprises a first switch that is connected to corresponding one of the M first light emitting diodes in parallel and configured to selectively enable a bypass current path;

a detection circuit configured to detect a current, flowing through one or more of the M first light emitting diodes, to produce a current detection signal when the input voltage is applied to the light emitting diode string;

a current control circuit coupled to the M-th first control circuit of the M first control circuits and the detection

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circuit and configured to in response to the current detection signal control the M-th first control circuit of the M first control circuits to provide a preset voltage to the first switch in the M-th first control circuit of the M first control circuits, so as to electively enable the bypass current path;

wherein when the first switch in the M-th first control circuit of the M first control circuits does not enable the bypass current path, in response to a potential of the input voltage the M-th first control circuit of the M first control circuits further selectively controls the (M-1)th first control circuit of the M first control circuits to provide the preset voltage to the first switch in the (M-1)th first control circuit of the M first control circuits, and M is a positive integer larger than 1.

2. The light emitting device according to claim 1, wherein when the first switch in the i-th first control circuit of the M first control circuits does not enable the bypass current path, the i-th first control circuit of the M first control circuits further in response to the potential of the input voltage selectively controls the (i-1)th first control circuit of the M first control circuits to provide the preset voltage to the first switch in the (i-1)th first control circuit of the M first control circuits, and i is a positive integer larger than 1 but smaller than or equal to M.

3. The light emitting device according to claim 2, wherein the i-th first control circuit of the M first control circuits further comprises:

a constant current source having two ends respectively coupled to the input voltage and a first node;

a first resistor having two ends respectively coupled to the first node and a second node; and

a second switch;

wherein the first switch in the i-th first control circuit of the M first control circuits is coupled to the second node of the i-th first control circuit of the M first control circuits and the second node of the (i-1)th first control circuit of the M first control circuits and in response to a potential of the first node of the i-th first control circuit of the M first control circuits, decides whether to electrically connect the second node of the (i-1)th first control circuit of the M first control circuits to the second node of the i-th first control circuit of the M first control circuits; and

the second switch of the i-th first control circuit of the M first control circuits is coupled to the first node of the i-th first control circuit of the M first control circuits and the first node of the (i-1)th first control circuit of the M first control circuits and in response to a potential of the second node of the i-th first control circuit of the M first control circuits, decides whether to electrically connect the first node of the (i-1)th first control circuit of the M first control circuits to the first node of the i-th first control circuit of the M first control circuits.

4. The light emitting device according to claim 3, wherein when the potential of the second node of the i-th first control circuit of the M first control circuits is larger than a related threshold, the second switch in the i-th first control circuit of the M first control circuits is turned on and the current control circuit, in response to the current detection signal, causes that the output current of the constant current source in the (i-1)th first control circuit of the M first control circuits flows to the current control circuit after flowing through the second switch in the i-th first control circuit of the M first control circuits; and

the potential of the second node of each of the M first control circuits is related to the input voltage.

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5. The light emitting device according to claim 3, wherein when a potential of the second node of the i -th first control circuit of the M first control circuits is smaller than or substantially equal to a related threshold, the second switch in the i -th first control circuit of the M first control circuits 5 is turned off, an output current of the constant current source in the $(i-1)$ th first control circuit of the M first control circuits flows through the first resistor in the $(i-1)$ th first control circuit of the M first control circuits so the preset voltage is applied to the first node of the $(i-1)$ th first control circuit of the M first control circuits. 10

6. The light emitting device according to claim 1, further comprising:

a second resistor having two ends respectively coupled to the light emitting diode string and the input voltage; and 15

a second control circuit coupled to the first one of the M first light emitting diodes and comprising a third switch connected to the second resistor in parallel,

wherein when the first one of the M first light emitting diodes does not emit light, the second control circuit turns on the third switch to enable the bypass current path for the second resistor. 20

7. The light emitting device according to claim 1, further comprising: 25

a second light emitting diode having two ends respectively connected to the light emitting diode string and the detection circuit.

8. The light emitting device according to claim 1, further comprising: 30

a third light emitting diode having two ends respectively connected to the node of the input voltage and the light emitting diode string.

9. The light emitting device according to claim 8, further comprising: 35

a compensation circuit coupled to the third light emitting diode and the current control circuit and configured to generate a compensation signal in response to a voltage difference between two ends of the third light emitting diode, 40

wherein in response to the compensation signal, the current control circuit further controls the M first control circuits to selectively enable the bypass current path.

10. The light emitting device according to claim 1, further comprising: 45

a temperature detection circuit coupled to the current control circuit and configured to detect a system temperature and generate a temperature detection signal according to the system temperature, 50

wherein, when the system temperature is higher than a temperature threshold, the current control circuit further controls the M first control circuits to enable the bypass current path in response to the temperature detection signal. 55

11. The light emitting device according to claim 1, further comprising:

an overvoltage protection circuit coupled to the node of the input voltage,

wherein, when the input voltage is larger than a voltage threshold, the overvoltage protection circuit set the input voltage to be at a low voltage potential. 60

12. A light emitting device with one or more low voltage-endurance components, the light emitting device comprising: 65

a light emitting diode string comprising M first light emitting diodes connected in series;

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a second light emitting diode directly connected to the M -th first light emitting diode of the M first light emitting diodes;

a third light emitting diode having two ends that are directly connected to the first one of the M first light emitting diodes and a node of an input voltage, respectively; and

M first control circuits, each of which comprises a first switch connected to corresponding one of the M first light emitting diodes and configured to selectively enable a bypass current path in response to a command of the corresponding first control circuit;

wherein when the input voltage is larger than a first threshold, the second light emitting diode and the third light emitting diode simultaneously emit light;

when the input voltage is larger than a second threshold larger than the first threshold, the M first control circuits respectively disable the bypass current paths sequentially so that the M first light emitting diodes sequentially emit light; and

M is a positive integer larger than 1.

13. The light emitting device according to claim 12, further comprising:

a detection circuit configured to detect a current, flowing through one or more of the M first light emitting diodes, to produce a current detection signal when the input voltage is applied to the light emitting diode string; and 50

a current control circuit coupled to the M -th first control circuit of the M first control circuits and the detection circuit and configured to in response to the current detection signal, control the M -th first control circuit of the M first control circuits whether to provide a preset voltage to the first switch in the M -th first control circuit of the M first control circuits, so as to selectively enable the bypass current path;

wherein when the first switch in the M -th first control circuit of the M first control circuits does not enable the bypass current path, the M -th first control circuit of the M first control circuits selectively controls the $(M-1)$ th first control circuit of the M first control circuits according to a potential of the input voltage to selectively provide the preset voltage to the first switch in the $(M-1)$ th first control circuit of the M first control circuits, and M is a positive integer larger than 1.

14. The light emitting device according to claim 13, wherein when the first switch in the i -th first control circuit of the M first control circuits does not enable the bypass current path, the i -th first control circuit of the M first control circuits selectively controls the $(i-1)$ th first control circuit of the M first control circuits to provide the preset voltage to the first switch in the $(i-1)$ th first control circuit of the M first control circuits according to the potential of the input voltage, and i is a positive integer larger than 1 but not larger than M . 55

15. The light emitting device according to claim 14, wherein the i -th first control circuit of the M first control circuits further comprises:

a constant current source having two ends respectively coupled to the node of the input voltage and a first node;

a first resistor having two ends respectively coupled to the first node and a second node; and

a second switch;

wherein the first switch in the i -th first control circuit of the M first control circuits is coupled to the second node of the i -th first control circuit of the M first control circuits and the second node of the $(i-1)$ th first control 65

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circuit of the M first control circuits and is controllable in response to the potential of the first node of the i-th first control circuit of the M first control circuits to electrically connect the second node of the (i-1)th first control circuit of the M first control circuits to the second node of the i-th first control circuit of the M first control circuits selectively;

the second switch in the i-th first control circuit of the M first control circuits is coupled to the first node of the i-th first control circuit of the M first control circuits and the first node of the (i-1)th first control circuit of the M first control circuits and is controlled by a potential of the second node of the i-th first control circuit of the M first control circuits to selectively and electrically connect the first node of the (i-1)th first control circuit of the M first control circuits to the first node of the i-th first control circuit of the M first control circuits.

16. The light emitting device according to claim 15, wherein when the potential of the second node of the i-th first control circuit of the M first control circuits is larger than a related threshold, the second switch in the i-th first control circuit of the M first control circuits is turned on and in response to the current detection signal, the current control circuit causes that an output current of the constant current source in the (i-1)th first control circuit of the M first control circuits flows to the current control circuit after flowing through the second switch in the i-th first control circuit of the M first control circuits; and

the potential of the second node of each of the M first control circuits is related to the input voltage.

17. The light emitting device according to claim 15, wherein when the potential of the second node of the i-th first control circuit of the M first control circuits is not larger than the related threshold, the second switch in the i-th first control circuit of the M first control circuits is turned off so that an output current of the constant current source in the (i-1)th first control circuit of the M first control circuits flows through the first resistor in the (i-1)th first control circuit of the M first control circuits to provide the preset voltage to the first node of the (i-1)th first control circuit of the M first control circuits.

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18. The light emitting device according to claim 12, further comprising:

a second resistor having two ends respectively coupled to the light emitting diode string and the node of the input voltage; and

a second control circuit coupled to the first one of the M first light emitting diodes and comprising a third switch connected to the second resistor in parallel,

wherein when the first one of the M first light emitting diodes does not emit light, the second control circuit turns on the third switch to enable the bypass current path for the second resistor.

19. The light emitting device according to claim 12, further comprising:

a compensation circuit coupled to the third light emitting diode and the current control circuit and configured to generate a compensation signal in response to a voltage difference between two ends of the third light emitting diode,

wherein in response to the compensation signal, the current control circuit further controls each of the M first control circuits to selectively enable the bypass current path.

20. The light emitting device according to claim 12, further comprising:

a temperature detection circuit coupled to the current control circuit and configured to detect a system temperature and produce a temperature detection signal according to the system temperature,

wherein when the system temperature is higher than a temperature threshold, the current control circuit further controls each of the M first control circuits to selectively enable the bypass current path according to the temperature detection signal.

21. The light emitting device according to claim 12, further comprising:

an overvoltage protection circuit coupled to the node of the input voltage,

wherein when the input voltage is higher than a threshold, the overvoltage protection circuit sets the input voltage to be at a low voltage potential.

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